

Cellulosic Biofuels: Review, Diagnosis, and Prescription

Lee R. Lynd

Thayer School of Engineering, Dartmouth College

Global Sustainable Bioenergy Project

Enchi Corporation

Drawing a Roadmap to Cellulosic Biofuel Deployment

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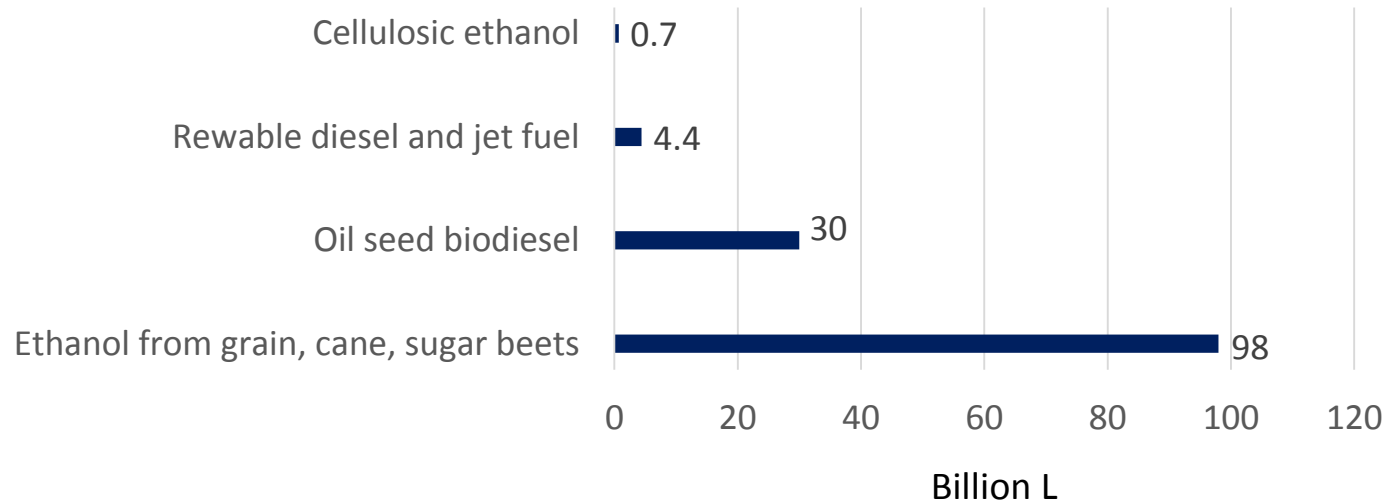
Global Sustainable Bioenergy



1. Review - the last decade

Biofuels Today

Global production capacity



Recent trends and developments

Renewable diesel and jet fuel: capacity grew by 30% in 2016

Cellulosic ethanol: 6 plants with capacity > 35 million L, but more capacity retired than added in 2016

1. Review - the last decade

Expectations

U.S. Cellulosic Biofuel Production (billion gallons or gallon equivalent, 2016)

Original RFS	Actual	
	Total	Liquid
4.5	0.16 ^a	~ 0.004

Sources: EPA, Bloomberg New Energy Finance

^a Includes biogas

Investment

10 years ago

Great expectations - "Greentech dwarfing IT"

Major investments by large & small companies

Today

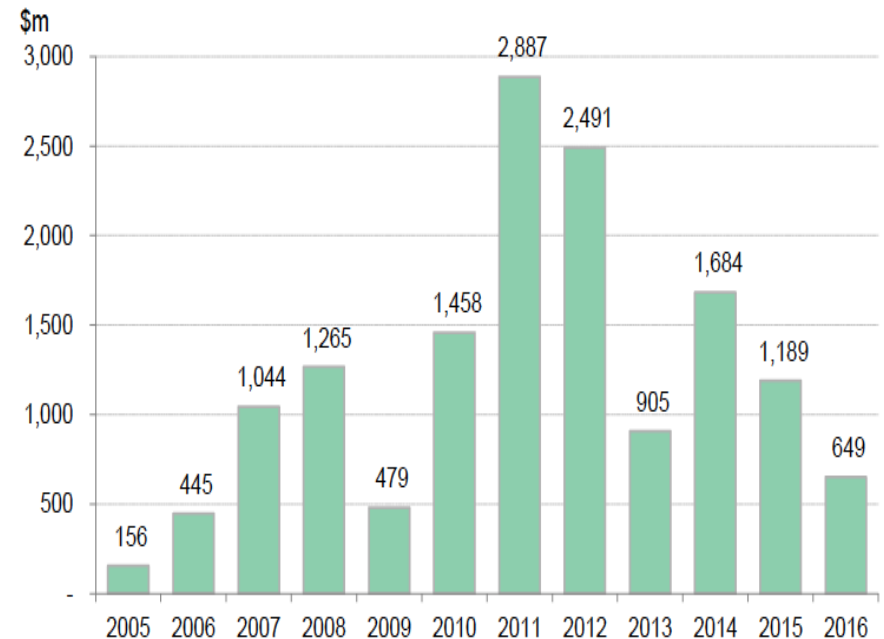
Advanced biofuel IPOs below their offering price

Several highly visible failures

Many surviving companies no longer in biofuels

Investor enthusiasm very low

Global Investment in Next Generation Biofuels and Biochemicals (Bloomberg NEF)



Boom, bust, & unmet expectations - albeit with some progress

2. Diagnosis

Importance of understanding and acknowledging shortcomings of 'Cellulosic biofuels 1.0'

- Investor reluctance (harder to raise expectations a second time)
- Identify what to change if different results are desired

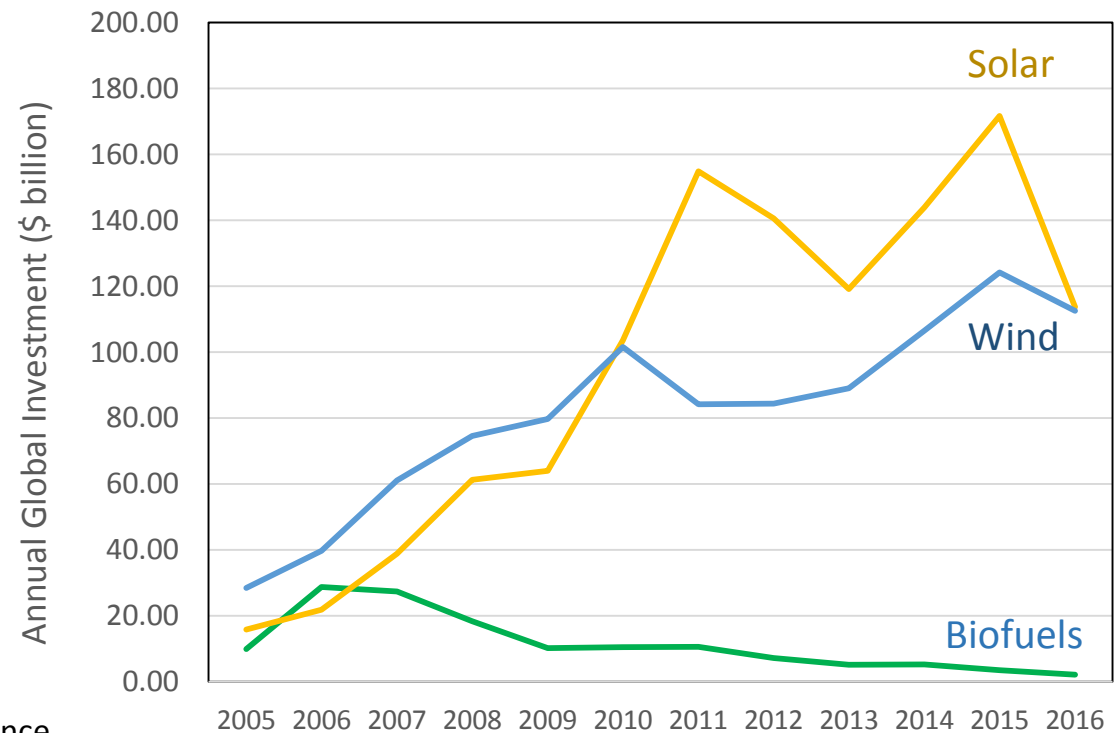
Headwinds

No carbon tax

Economic crash of 2008-2009

Unconventional gas and oil

We must look beyond these factors to explain cellulosic biofuels falling short of expectations



Sources: Bloomberg New Energy Finance

2. Diagnosis

Industry-specific explanations for cellulosic biofuels slow progress

Technological readiness overestimated

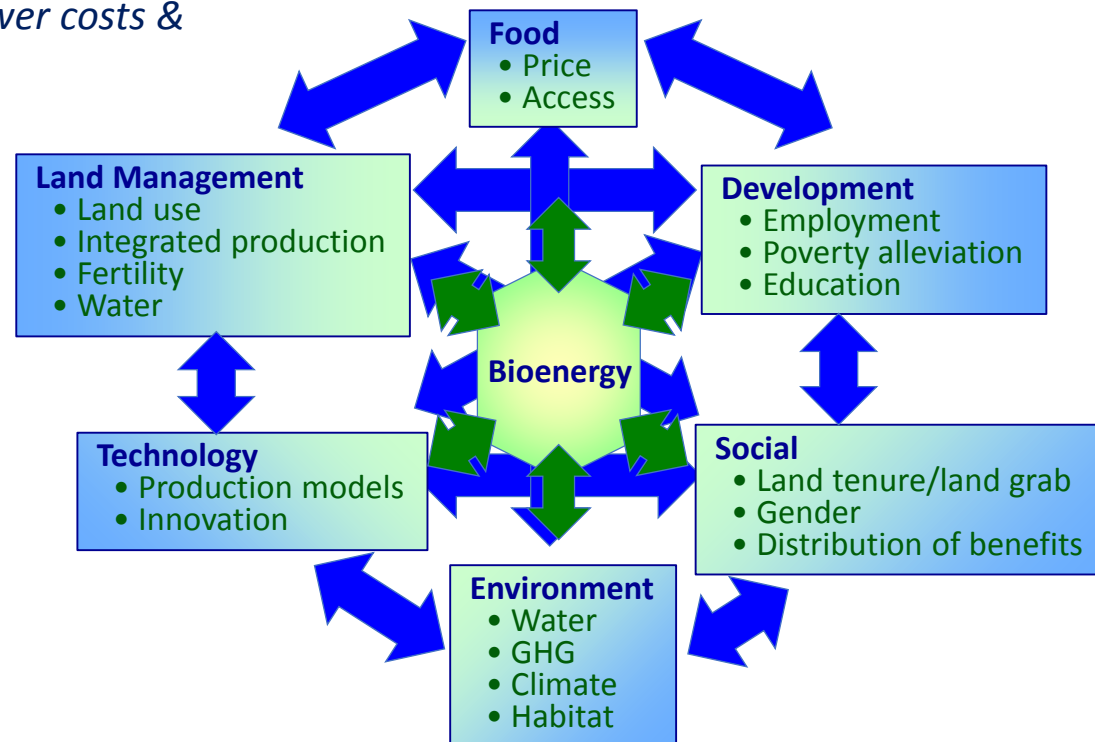
- Marked tendency, encouraged by both government and private investors, to focus on large, stand alone facilities rather than niche applications.
- Funding agencies prematurely turned away from cellulosic ethanol although it is now clear that further development is needed to achieve cost-competitive production even with oil at \$100/barrel
- Amidst frequent claims that economically viable technology was in hand and only needed investment in scale-up and commercialization, investment in new, potentially low-cost processing paradigms was generally modest, technological advancement was slower than it might have been, and policies were designed assuming that deployment rather than technology was the limiting factor.

Other renewable energy technologies proceeded in a stepwise fashion, recognized the need for technological advancement and invested accordingly, and benefitted from projects with lower costs & more rapid learning cycles.

Land issues – food, carbon, habitat, impacts on the disenfranchised

- Biofuels have more connections to more things we care about than other renewable energy technologies
- Advocates see opportunities for added benefit, critics see reasons for concern
- The critics have spoken more loudly

Others? Suggestions welcome



3. Prescription

In general

Recognize that cellulosic biofuels likely must be deployed on a large scale in order to achieve a low-carbon economy. Other options entail greater risks, and are arguably irresponsible to rely on.

... but we should not expect to achieve ultimate embodiments all at once.

We cannot afford another decade like the last if biofuels are to be on schedule for a 2 degree future.

Technological innovation – involving both current and new processing paradigms – is essential.

Achieving social and environmental benefits beyond energy supply is quite possible but will be achieved most fully and rapidly with intent.

Be open to change, because what we have been doing has not met expectations

In particular

Action Needed	Why other actions are also needed
1) Pursue commercial deployment in achievable, successively-enabling steps, proceeding from where the industry is today.	Incremental improvements may well not be sufficient to realize cost-competitiveness and/or fully realize potential (see 3)
2) Maximize social and environmental benefits drawing from on-the-ground examples and experience.	Sustainability is a necessary but not sufficient condition for industry expansion. Better technology is also needed (see 1 & 3).
3) Invest in innovation pursuant to alternative processing paradigms offering potential for large cost savings.	There are opportunities to advance existing new paradigms as well as new ones (see 1).